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ARTHUR BEVAN, *State Geologist*

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Chloride in Ground Water in the Coastal Plain of Virginia

By

D. J. CEDERSTROM

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COMMONWEALTH OF VIRGINIA

VIRGINIA GEOLOGICAL SURVEY

UNIVERSITY OF VIRGINIA

CHARLOTTESVILLE, VA., March 30, 1943.

To the Virginia Conservation Commission:

GENTLEMEN:

I have the honor to transmit and recommend for publication as Bulletin 58 of the Virginia Geological Survey series of reports the manuscript and illustrations of a report on *Chloride in Ground Water in the Coastal Plain of Virginia,* by Mr. D. J. Cederstrom of the Federal Geological Survey.

The author in this summary report discusses the amount and the distribution of chloride in the ground water of the Virginia Coastal Plain. Especial attention is given to the areas containing high percentages of chloride which are detrimental to the use of that ground water for industrial, naval, military and domestic purposes.

The regional investigation of ground-water supplies and their geologic relations in the Coastal Plain of Virginia is a cooperative project between the State Geological Survey and the Federal Geological Survey. This brief report on a part of the investigation is published so that the essential information on the chloride will be promptly available to industries, municipalities, and units of the armed forces. Reports on the major project will be published later as bulletins of the Virginia Geological Survey.

Respectfully submitted,

ARTHUR BEVAN,
State Geologist.

Approved for publication:
Virginia Conservation Commission,
Richmond, Virginia, March 31, 1943.
R. A. GILLIAM, *Executive Secretary and Treasurer.*

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By D. J. Cederstrom[1]

ABSTRACT

The occurrence of Virginia Coastal Plain waters which contain more than 40 parts per million of chloride and the means of maintaining supplies of reasonably good quality in those areas where the chloride content is high are discussed.

The Coastal Plain of Virginia is underlain by beds of unconsolidated clay, sand and marl which dip gently seaward. The beds thin westward along the Fall Zone and thicken eastward until at Norfolk they are about 2200 feet thick. Above the granitic basement rock the sediments include Lower Cretaceous sand and clay of the Potomac group, Upper Cretaceous sand and clay, glauconitic sand and marl of the Pamunkey group of Eocene age, marl and sandy marl of the Chesapeake group of Miocene age, and terrace sand and clay of the Columbia group of Pleistocene age. This report deals mostly with the artesian waters obtained from the Potomac and Pamunkey groups of formations. In addition to a seaward dip, the strata are locally warped. Artesian waters in places contain a high chloride content because the water-bearing strata have never been completely flushed of the sea water with which they were once saturated. The brackish waters occur apparently in a prominent down-warped basin where heavier salty waters in the basin have more or less inhibited circulation. In that area fresh waters moving eastward down the dip of the strata have been diverted to the southeast and northeast.

Waters containing more than 40 parts per million of chloride occur in a wedge-shaped area between the Rappahannock and James rivers, the apex of which is at Toano, James City County. Within the wedge-shaped area an intermediate border zone is marked off in which chlorides do not exceed 250 parts per million. Within the inner higher chloride zone waters contain up to several thousand parts per million of chloride. Artesian waters containing up to 500 parts per million can be and are used for domestic, municipal, industrial, and naval and military supplies although less than 250 parts per million is generally considered desirable. In, or immediately outside of, the wedge-shaped area of brackish water, overpumping will tend to increase the chloride content.

[1] **Associate Geologist, U. S. Dept. Interior, Geological Survey.**

The discussion is based on a study of old and recent analyses of well waters, pump tests, and the correlation of chloride increases with the decline of water levels. Information is given on the proper procedure in developing large well-water supplies in or near the high chloride zone and the dangers to be avoided.

A section on the occurrence of chloride in shallow well waters in coastal areas is included.

INTRODUCTION

Large supplies of ground water have been obtained at many places in the Coastal Plain of Virginia for industrial, municipal, naval and military use (Pls. 1 and 2). The need of maintaining supplies of satisfactory quality and of obtaining additional supplies has focussed attention upon the quality of water available. The most troublesome constituent is chloride, generally present in ground water as sodium chloride (common salt). This paper deals with the areal distribution of chloride waters of various concentrations and contains a discussion of problems which are, or might be, encountered in the development of ground water in and near the high chloride zone. The data presented may, therefore, be used as a guide with reference to chloride content where the development of supplies of ground water may be contemplated.

Artesian waters which are yielded to wells penetrating sands of the Potomac group of Lower Cretaceous age in the Coastal Plain province of Virginia are discussed in some detail. Most of the emphasis is placed on those areas within which, or adjacent to which, artesian waters contain objectionable amounts of chloride. A brief discussion of the chloride content of waters obtained from shallow wells is also given.

SOURCES OF DATA

In 1918, W. T. Lee, R. D. Mesler, W. C. Mansfield, and A. G. Maddren, all of the U. S. Geological Survey, made a brief study of the geology and ground-water resources of the countries bordering the Chesapeake Bay on the west and south because of the need for such information during the first World War. Those data were not published, but the analyses of many of the water samples[2] which were collected have been particularly important in the study of changes of chloride content which have taken place since that time. Data on wells and water in the counties of the Coastal Plain, published by Sanford[3], have also been freely used in this report.

[2] Riffenburg, H. B., The chemical character of ground water in the Coastal Plain of Virginia: U. S. Geol. Survey, unpublished manuscript, 1918.

[3] Sanford, Samuel S., The underground water resources of the Coastal Plain of Virginia: Virginia Geol. Survey Bull. 5, 1913.

Pertinent information which was collected by the writer during the course of a detailed and systematic study of the ground-water resources of the Coastal Plain area south of James River[4] as part of a cooperative project by the State and Federal geological surveys, has been incorporated in this paper. Miscellaneous unpublished data obtained as a result of studies made of local areas, particularly in the York-James peninsula, have also been included. Some field work has been done for the specific purpose of determining whether the chloride content of waters from artesian wells in eastern Virginia has increased since they were sampled during the course of earlier studies.

The writer expresses his appreciation to many individuals who have supplied data used in this report, or who have been otherwise helpful. Mr. James Pharr, Chemist, Newport News Water Commission, at Lee Hall, Va., supplied data on wells, assisted in the collection of samples for analysis by the Federal Geological Survey, and furnished supplementary analyses of waters from wells at Lee Hall and Skiffs Creek, made by himself and others. Mr. Thomas Keane, Assistant Sanitary Engineer, United States Corps of Engineers, Fort Eustis, Va., has been responsible for the regular collection of samples at Fort Eustis and has been most helpful in other ways. Mr. Elbert Cox, Superintendent, Colonial National Historical Park, Yorktown, Va., has made possible the regular sampling of the Park well and consequent acquisition of particularly valuable data. A great many other individuals have contributed valuable information of one type or another, which is hereby gratefully acknowledged. Particular thanks are due to various well drilling organizations which have supplied fundamental data. These are the Layne-Atlantic Company, of Norfolk, Va.; Jesse Minton of Smithfield, Va.; Mitchells Pump and Well Company, of Petersburg, Va.; and the Sydnor Pump and Well Company and the Virginia Machinery and Well Company, of Richmond, Va.

Acknowledgments are also due for suggestions and critical readings of this manuscript, to the various members of the Ground-Water Division of the Federal Geological Survey, O. E. Meinzer, Geologist-in-Charge; and members of the Geological Survey, Virginia Conservation Commission, Arthur Bevan, State Geologist.

OUTLINE OF GEOLOGY

The Coastal Plain province of Virginia is underlain by unconsolidated clays, sands and marls which dip gently seaward (Fig. 1). Westward these sediments thin to a feather edge along the Fall Zone which extends approximately north-south in Virginia and passes through Emporia, Petersburg, Richmond, Fredericksburg,

[4] Cederstrom, D. J., Ground-water resources of the southeastern Virginia Coastal Plain: Virginia Geol. Survey Circ. 1, 1941; also unpublished manuscript.

and Washington, D. C. Along the Fall Zone the granitic rock which underlies the unconsolidated sediments is close to the surface. In places where the thin cover of sediments has been removed by erosion, the granitic rock is exposed. East of the Fall Zone the basement rock lies at progressively greater depths and the unconsolidated sediments thicken to more than 2000 feet, as at Norfolk and Mathews Court House. The sediments of the Coastal Plain extend eastward from the shore of the Atlantic Ocean to the edge of the continental shelf where they are known to be about 12,000 feet thick.[5]

Alternating sands, clays, and sandy clay of the Potomac group of Lower Cretaceous age rest upon the granitic bedrock. This group of sediments is nonmarine in origin. The sands included in the group are prolific water bearers. Above the Potomac group of sediments, alternating marine sands and clays of Upper Cretaceous age are present. As shown in Figure 1, these sediments are thin and do not extend westward to the Fall Zone. The Upper Cretaceous sands appear to be somewhat inferior water bearers.

The Pamunkey group of Eocene formations rests upon the Cretaceous sediments. These are marine sediments which consist largely of glauconite sands (referred to as "black sands" by the driller), glauconitic quartz sands, glauconite marls and marls. Thin consolidated limy strata are not uncommon and in some places quartz sands or clayey strata are present. In the area north of York River the glauconite and quartz sands of the Pamunkey group are commonly developed as a source of ground water. South of the York, deep wells almost everywhere penetrate the underlying Potomac group of sediments. Where both Potomac and Pamunkey strata are water-bearing, for the purpose of this report they may be considered as a unit since in the two formations no great differences in quality of water are apparent, except those differences which may be ascribed to differences in depths of the wells.

The Chesapeake group of marine marls and subordinate sandy formations overlies the Pamunkey group of sediments. Relatively shallow wells obtain water from the sandy members of this group in the area bordering Chesapeake Bay. Although under slight artesian head, wells penetrating this formation are not generally spoken of as "artesian" and are not included in this paper in the discussion of water from wells penetrating the Pamunkey and Potomac groups of sediments.

The entire Coastal Plain province is veneered by the Columbia group of terrace sands and clays of Pleistocene age. The

[5] Ewing, Maurice, Crary, A. B., Rutherford, H. M., and Miller, Benjamin, Geophysical investigations in the emerged and submerged Atlantic Coastal Plain: Geol. Soc. America Bull., vol. 48, pp. 753-812, 1937.

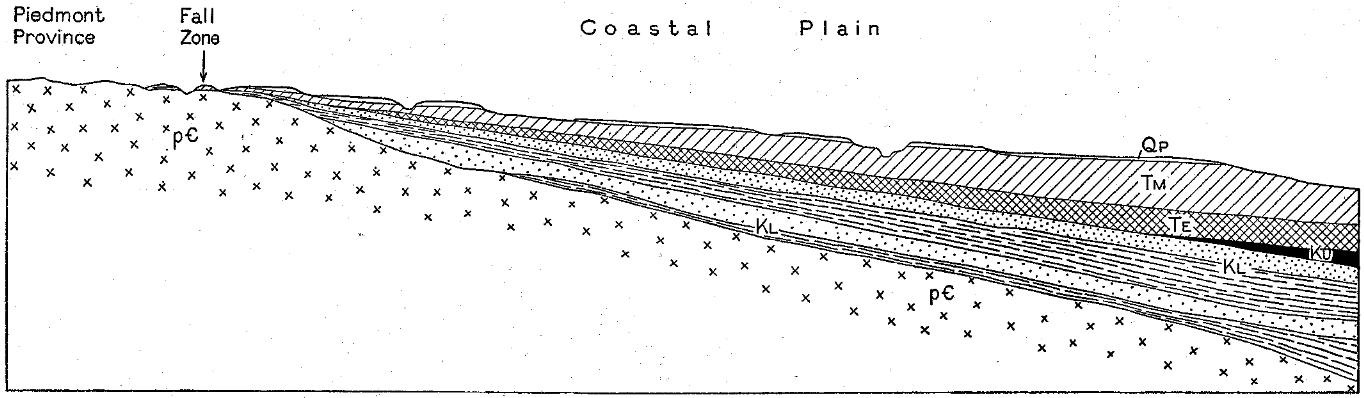


FIGURE 1.—Generalized section of the Virginia Coastal Plain. Qp, Pleistocene terrace formations (Columbia group); Tm, Miocene marl (Chesapeake group); Te, Eocene glauconitic sand and marl (Pamunkey group); Ku, Upper Cretaceous sands and clays; Kl, Lower Cretaceous sands and clays (Potomac group); p€, Crystalline basement rock, chiefly pre-Cambrian.

sediments on the higher terraces are continental in origin whereas those on the lower easterly terraces are marine. Thousands of shallow dug or driven wells obtain small supplies of water from the terrace sediments throughout the Coastal Plain. Water from wells developed in the Columbia terrace formations and from underlying formations of the Chesapeake group is briefly discussed in the chapter entitled "Chloride content of shallow ground water."

As shown in Figure 1, the Coastal Plain sediments dip seaward at a slope of about 10 feet per mile.[6] The seaward slope is not uniform, however, and locally strata may be higher or lower with respect to sea level than they are a short distance to the south or north. Such data as are available indicate that the sediments in the peninsular area between the James and Rappahannock rivers are downwarped with respect to identical or similar beds south of the James and north of the Rappahannock. Less prominent warpings of Coastal Plain sediments are known elsewhere.

The area considered in detail is shown in Plate 3. It comprises the larger part of the Coastal province of Virginia. The Eastern Shore peninsula is not considered in detail because of the absence there of wells penetrating Cretaceous sands. Those parts of the Coastal Plain which lie to the west and north of the area shown on the map are not discussed because in those areas the chloride content of artesian water is everywhere low and no problems of chloride increases are apparent.

In the western portion of the area shown in Plate 3, the uppermost artesian water-bearing sands of the Potomac or Pamunkey groups lie generally 200 or more feet below the surface. Due to their seaward slope these strata may lie 700 feet or more below the surface along Chesapeake Bay.

OCCURRENCE OF ARTESIAN WATER

Water which more or less fills the surficial formations everywhere in eastern Virginia is not considered here, but rather the confined water which is present in deeper sands of the Potomac group. These sands are saturated with water back to the Fall Zone where they lie close to, or at, the surface and thus receive recharge from rain which falls upon or percolates into them. Since the saturated sands extend westward to higher elevations, the water in them is under pressure and will rise in wells that penetrate the formation. Where the land surface is low, water may flow from the wells, but where the land is higher, the water may have to be pumped.

[6] Cederstrom, D. J., Geology and artesian water resources of a part of the southern Virginia Coastal Plain: Virginia Geol. Survey Bull. 51-E, p. 129, 1939.

CHLORIDE IN ARTESIAN WATER

ORIGIN OF CHLORIDE

It is not the purpose of this paper to discuss the origin of the chloride-bearing waters in detail.[7] It is believed that the salinity of the artesian waters of the Virginia Coastal Plain is due to incomplete flushing of these strata since they were last saturated with sea water. In this belief the writer concurs with Sanford.[8] The Coastal Plain formations extend to the continental shelf, many miles out to sea, and along that shelf the strata may be open to strictly marine waters. However, migration up dip of marine waters is prevented by the artesian water which is present under pressure and tends to force the sea water out. In the entire area west of the continental shelf and extending back almost to the Fall Zone, the Potomac strata are, as far as is known, everywhere blanketed off from surface waters of all kinds by thick and practically impermeable beds of marl.

FACTORS DETERMINING OCCURRENCE OF HIGH CHLORIDE WATER

Waters containing from 40 to more than 1000 parts of chloride are found in many places in eastern Virginia. In southeastern Virginia, the area of high chloride water in the sands of the Potomac group begins about 50 miles east of the Fall Zone; in east-central Virginia, it begins about 30 miles east of the Fall Zone; and in the northeastern part of the area covered in this report, the boundary of the high chloride area projected northward indicates that high chloride artesian water may be expected to occur east of a point 15 miles east of Reedville in Northumberland County or 80 miles east of the Fall Zone. Thus the area within which high chloride artesian water is found has the form of a wedge, the apex of which is near Toano in western James City County (Pl. 3).

West of this wedge-shaped area the chloride content of artesian water from both deep and relatively shallow formations is much the same. At Franklin, Southampton County, a well 150 feet deep yields water containing 2 parts per million of chloride (Table 11) and a deep well at Franklin, Isle of Wight County, which obtains most of its water from strata from 360 to 600 feet below the surface, yields water containing only 10 parts per million chloride (Pl. 2A, Table 2). At Bacons Castle, Surry County, strata at 550 feet below the surface contain about the same amount of chloride as strata 360 feet below

[7] For a thorough discussion of the relationship of fresh water to salt water, see Barksdale, H. C., and others, Supplementary report on the ground-water supplies of the Atlantic City region: New Jersey State Water Policy Commission Special Rept. No. 6, 1936; and Brown. J. S., A study of coastal ground water with special reference to Connecticut: U. S. Geol. Survey Water Supply Paper 537, 1925.

[8] Sanford, Samuel S., The underground water resources of the Coastal Plain province of Virginia. Virginia Geol. Survey Bull. 5, p. 14, 1913.

the surface (Table 12). At West Point, King William County, similar conditions were found (Table 4). At Walnut Point, Northumberland County, a well 605 feet deep yields water containing 1.3 parts more than the water obtained from a well 340 feet deep (Table 10). One exception has been noted: at South Quay, Nansemond County, a well 427 feet deep yields water containing 34 parts of chloride or 30 parts more than a well 235 feet deep (Table 8).

Within the wedge-shaped area of high chloride water the water from the deeper strata almost everywhere has an appreciably higher chloride content than water from the shallower strata. For example, Darton[8] notes that water yielded by the deep well at the Norfolk City waterworks increased from 757 parts of chloride at 730 feet to 1112 parts at 1070 feet (Table 9). In northern Nansemond County the wells yielding water with from 50 to 200 parts of chloride are generally appreciably deeper than wells in which the chloride content is negligible.

In summary, then, it would appear that in the process of flushing by fresh waters entering the formations from the west, the brackish waters have been effectively moved out of both to deep and shallow strata throughout a large part of the Coastal Plain. Where flushing has not been complete, fresh waters have tended to move into the upper rather than the lower strata because of differences in specific gravity between fresh and saline water. As a result, the brackishness of the water in any given stratum increases down dip and at any given location it increases with depth.

CHLORIDE ZONES

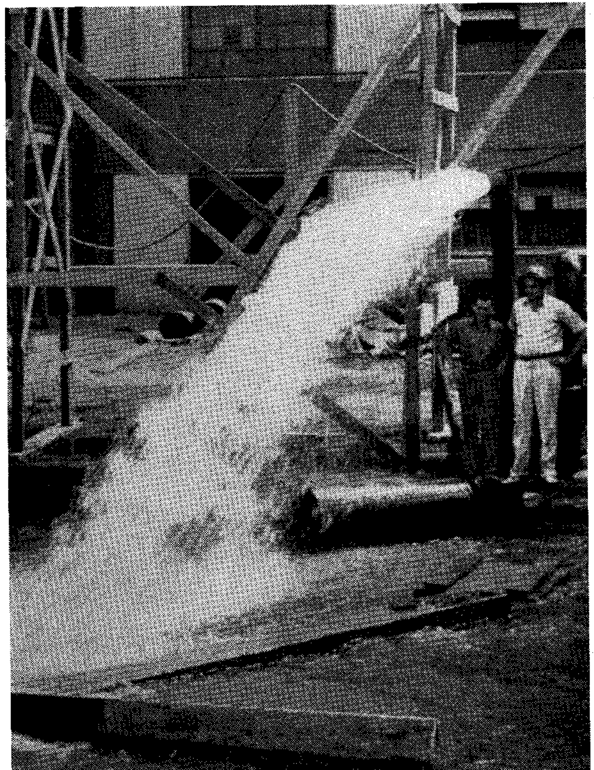
It is shown in Plate 3 that areas of low, intermediate, and high chloride waters from the Potomac and Pamunkey formations may be accurately indicated. The area in which artesian waters contain 40 or more parts per million of chlorides has the form of a broad wedge, the apex of which is near Toano in western James City County. Northwestward the boundary of the high chloride zone extends through western Gloucester County and eastern Middlesex County and crosses the spit of land east of Taft, Lancaster County. Southeastward from Toano this boundary approaches the tip of Hog Island and lies along the course of James River. It trends south-southeastward below Battery Park, Isle of Wight County, and crosses the eastermost portion of that county and northern Nansemond County.

Low chloride zone.—The westerly and northerly area, in which the chloride is less than 40 parts per million, has been discussed in part. In this zone the chloride content of most artesian waters ranges

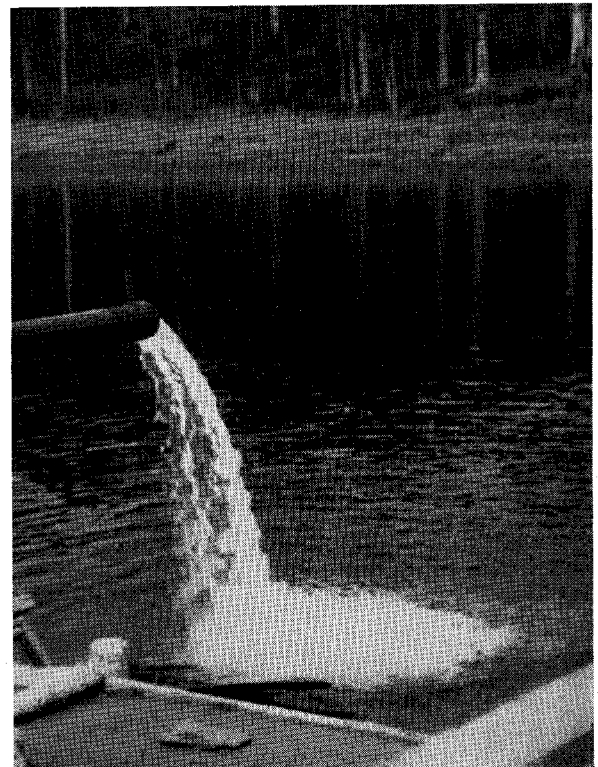
[8] Darton, N. H., U. S. Geol. Survey Geologic Atlas, Norfolk folio (No. 80), p. 4. 1902.

Automatic water-level recorder over well with extended casing.

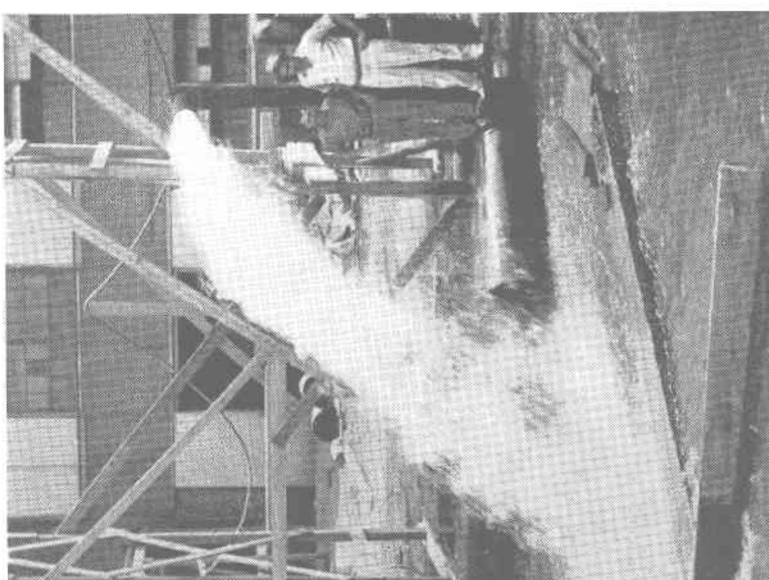
Automatic water-level recorder over well with extended casing.



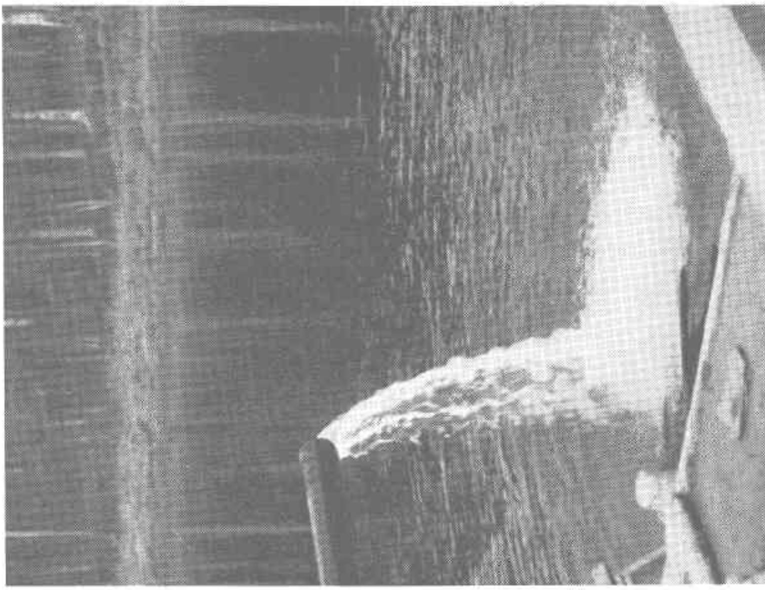
A. Deep well furnishes industrial water supply at Franklin.



B. Ground water used to supplement a surface water supply.



A. Deep well furnishes industrial water supply at Franklin.



B. Ground water used to supplement a surface water supply.

from 1 to 20 parts per million, but in some places the chloride content is between 20 and 40 parts per million. The only place known thus far where a water in this area contains more than 40 parts per million of chloride is about 7 miles south of Franklin where one well yields water containing 88 parts per million of chloride. As far as available data indicate, deeper strata in the low chloride zone generally contain only slightly more chloride than the shallower strata. Slight variations in chloride content in the low chloride area have probably resulted from variations in flushing action due to differences in lithology, artesian head, and other factors.

It appears desirable that large well installations in the low chloride zone which are intended to withdraw millions of gallons of water a day continuously should be located at least a few miles distant from the border of the intermediate belt in order that movement of water from the higher chloride area into the well field be kept at a minimum. In most instances it would probably be desirable that the nearest well be 5 miles from the boundary of the intermediate chloride zone shown in Plate 3. The relationship of the water-bearing formations to be drawn upon to any nearby formations known to contain salt water should be determined; in some instances this may necessitate test drilling outside the producing well field. The location of brackish water and the degree of brackishness in sandy strata deeper than those drawn upon in the producing well field should be determined in order to evaluate the possibilities of migration of higher chloride waters from depth under conditions of heavy pumping. Observation wells should be maintained by means of which any movement of higher chloride waters towards the well field could be observed. By taking this precaution, any danger of chloride contamination would be recognized at an early stage and could be dealt with accordingly.

Intermediate chloride zone.—The zone in which chlorides do not exceed 250 parts is shown in Plate 3 because this amount of chloride is generally considered to be the minimum amount which can be detected by taste. Hence moderate quantities of artesian water may generally be developed in this zone. Waters in this zone, however, generally contain a rather high amount of sodium bicarbonate and lesser amounts of other constituents which make it unfit for some industrial uses without treatment. Williamsburg is supplied with water containing 225 parts per million of chloride.

Field analyses of a number of waters from Nansemond County illustrate the difficulty of drawing a sharp boundary in some areas. In the northern part of the county wells deeper than the average well in the intermediate zone, as shown on the map, yield water containing more than 40 parts per million of chloride. The generalization is thereby borne out that within the high and intermediate chloride zones wells drawing from the deeper strata will yield water containing a higher chloride content. As a safety factor, the zonal boundaries have been drawn on the basis of the maximum chlorides found.

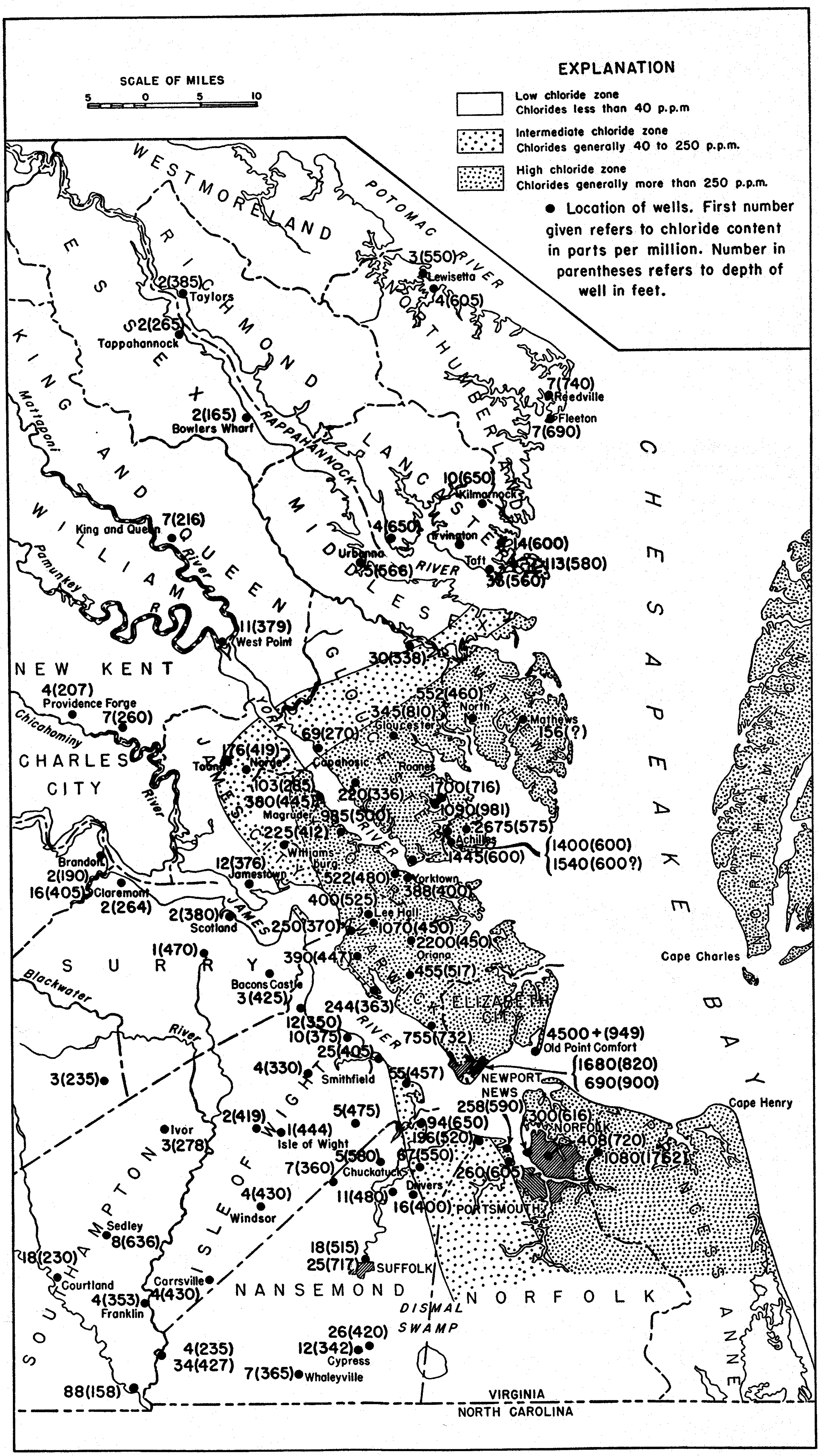
Large quantities of water should not be developed in the intermediate zone because, under conditions of heavy pumping, water of excessive chloride content may migrate into the well field, or be drawn up from greater depths, and the water supply may thus be rendered unfit for use. The limit of safety is not known, but it is thought that not much more than one million gallons a day should be developed in any one community or city.

High chloride zone.—In Plate 3 it is shown that waters with a chloride content in excess of 250 parts per million is present in the area bounded by a line drawn from the easternmost tip of Lancaster County southwestward to a point a few miles north of Williamsburg and thence southeastward from that point more or less parallel to the north bank of James River to Portsmouth, Norfolk County. This area includes Mathews County, southeastern Gloucester County, most of York and Warwick counties, all of Elizabeth City County, eastern Norfolk County, and all of Princess Anne County.

In this area the chloride content of artesian water may exceed several thousand parts per million although, near the western edge of the zone, the water commonly contains less than 1000 parts. As in the intermediate zone, deeper strata at any given locality yield water of higher chloride content than wells developed at slightly lesser depths in the same sands a short distance away. Similar variations have been noted in the Magruder-Williamsburg area. At Lee Hall reservoir one well yields water containing 1050 to 1100 parts of chloride and a second well of about the same depth penetrating the same stratum 1 mile to the southwest yields water containing less than 750 parts of chloride.

It seems that much of the variation in a particular stratum or zone of sands is a progressive increase in mineralization towards the down-warped basin of high chloride waters. The progressive increase of mineralization is not necessarily a function of the increased depth of the water-bearing stratum but seems rather to be a function of decreased flushing by fresh waters from the west as the axial portion of the down-warped basin is approached.

In some places there does not seem to be a reasonable explanation of marked variations that occur within very short distances. At Newport News the Buxton Hospital well, 820 feet deep, yielded water containing 1680 parts per million of chloride, whereas the



Map showing occurrence of chloride in artesian water in the Virginia Coastal Plain south of Potomac River.
By D. J. Cederstrom.

Levinson Meat Packing Company well apparently obtains water from about the same depth which contains only 690 parts of chloride. (See Table 13.) In southeastern Gloucester County no particular relationship between depth and chloride content can be discerned as all waters from deep wells seem to be particularly high in chloride.

At Yorktown wells yield water containing less than 600 parts per million of chloride but at the Bectel Farm, a few miles up river, a well which presumably taps the same stratum as the Yorktown wells, yields water containing 985 parts of chloride. (See Table 14.) This particular variation may be due to contamination of the strata by river water through old abandoned wells with leaky casings.

In central Gloucester County and in that part of northern York County bordering York River, some wells within the high chloride zone yield water containing less than 250 parts per million of chloride. These wells obtain water from basal Miocene or upper Eocene formations. The zonal boundaries (Pl. 3) have been drawn on the basis of the higher chloride content characteristic of water from the Lower Cretaceous sediments in these areas.

Considering the zone as a whole, it may be said that artesian water should not be developed in it unless other sources of water are not available. On the other hand, in spite of the quality of water in this zone, much good use has been made of that which has been obtained. At Fort Eustis and Lee Hall excellent use is made of quantities of ground water containing as much as 500 parts per million of chloride. At Camp Peary, near Williamsburg, water containing from 300 to 400 parts per million of chloride has been found satisfactory. At Yorktown, water containing from 400 to 500 parts per million of chloride has been satisfactorily mixed from time to time with spring supplies, when those supplies have been insufficient to meet the demand. The municipal supply of the town of Gloucester contains 345 parts of chloride. High chloride water is used for cooling at a meat packing company at Newport News, and at West Norfolk, a high chloride water is treated and used for boiler feed. By and large, however, water containing more than 250 parts per million of chloride is considered undesirable and considerable effort has been made, and rightly so, in the high chloride area to obtain water from shallower wells, from streams, or from sources outside the area.

RELATION OF HIGH CHLORIDE WATER TO GEOLOGIC STRUCTURE

As far as detailed data are available, it is clearly evident that at the same distance east of the Fall Zone the formations in the York-James Peninsula lie at lower elevations than the same forma-

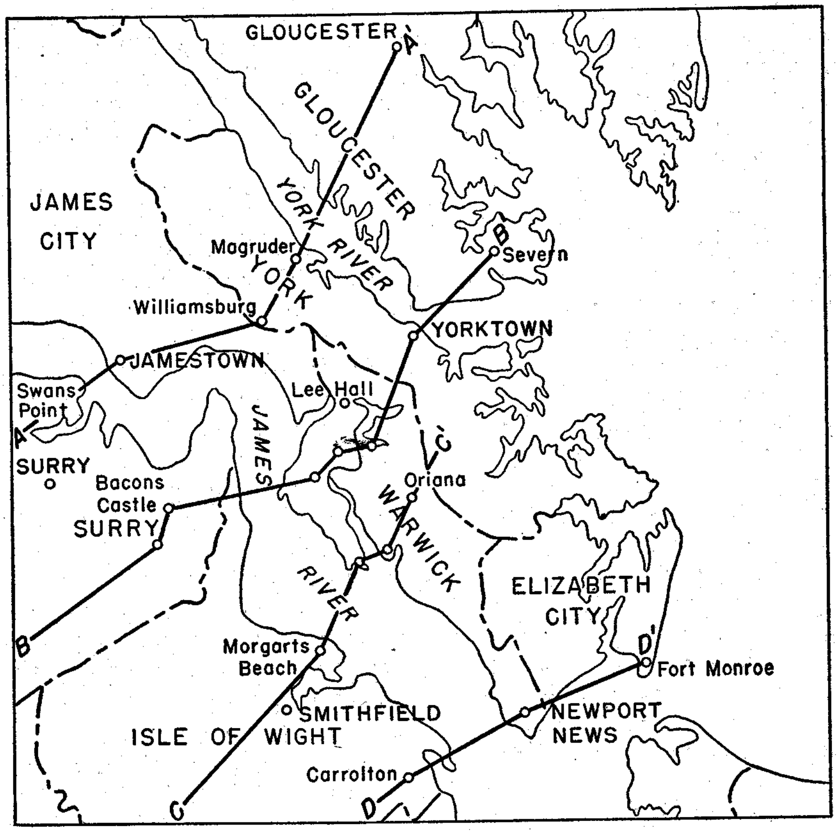


FIGURE 2.—Map showing locations of cross sections (Plate 4).

tions south of James River. The formations south of James River in northeastern Surry and Isle of Wight counties generally dip northeast from 5 to 10 feet per mile. Northeast of the James, however, the dip of the formations tends to increase sharply and locally it may be more than 25 feet per mile. This general downwarping is shown in Plate 4. As shown in section B-B′ (Fig. 2), steepening of the dip northeast of Mulberry Island indicates a local syncline, the axis of which passes through Layne No. 3 well at Fort Eustis. Other data, not plotted on the cross section, indicate that the axis of the syncline may be even lower than shown and that the structure might be interpreted as a fault. Although the general northeastward dip of the key horizons in section B-B′ is interrupted across the York-James peninsula, that dip is continued from Yorktown to Severn. A local steepening of a generally gentle northeastward dip in the same section is seen between test wells Nos. 1 and 2 at Bacons Castle.

In section A-A′, the low dip of the formations southwest of James River is continued through Jamestown and Williamsburg, but the dip steepens from a point northeast of Magruder to Gloucester. In section C-C′, the dip of the formations increases northeast of Morgarts Beach. From Curtis Point to Menchville a local excessively high dip appears to be present, similar to that seen in section B-B′ east of Mulberry Island. In section D-D′, tentative correlations of the beds indicate that the base of the Eocene dips northeast about 40 feet a mile from Carrolton, Isle of Wight County, on the south bank of the James through Newport News to Fort Monroe.

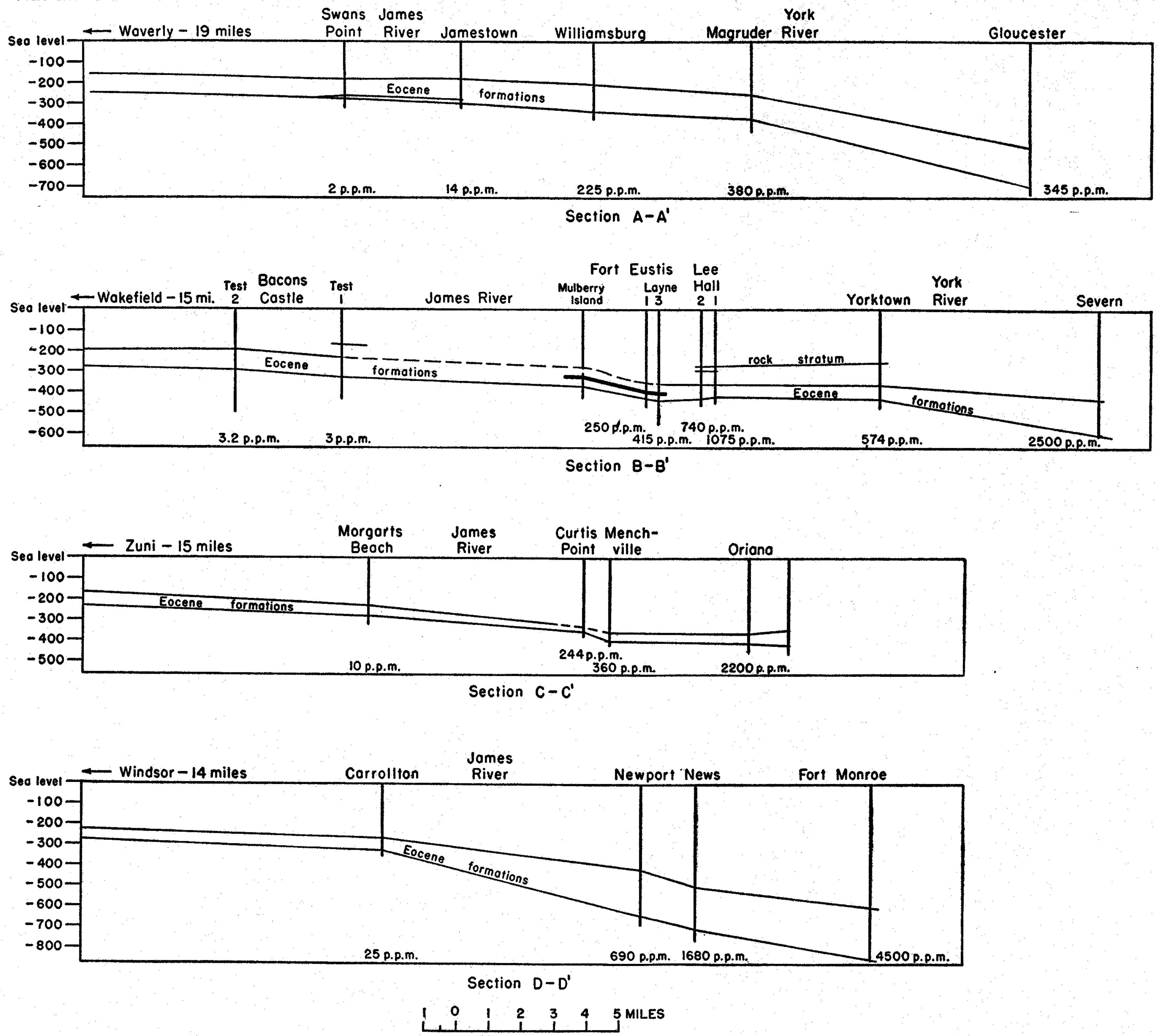
Study of relatively few logs of wells in the counties north of Gloucester County indicates that the dip of the formations in the northeastern part of the Coastal Plain is to the southeast. A structural contour map drawn on the base of the Eocene would show contours that extend north and south but with a marked westward divergence of that trend in the York-Rappahannock peninsula. Data at hand show with a fair degree of certainty that the contours drawn on the base of the Eocene formations at depths of 600 and 700 feet below sea-level trend south-southwestward across the end of the York-Rappahannock peninsula to Gloucester, and more or less south-southeastward from Gloucester across the end of the York-James peninsula through Norfolk. Sufficient data to complete the interpretation of the structure north of the York River are not available, but a working hypothesis based on the available data is as follows: Throughout the western and central parts of the Virginia Coastal Plain the older sedimentary formations (Potomac group) tend to dip very gradually seaward; the strata are warped, however, and viewed in the north-south cross section might have the aspect of terraces of various elevations. At points from 25 to 50 miles east of the Fall Zone these "terraces" seem to merge on the common steeper slope of which the contours at 600 and 700 feet below sea level have been described.

Although this description of the structure is necessarily sketchy, it indicates the relationship of the high chloride areas to the geologic conditions. The water-bearing sands in the York-James peninsula have been warped down to lower elevations than in the area south of the James (Pl. 4) in consequence of which these strata contain water of higher chloride content. The migration of fresh water down dip has been somewhat inhibited where heavier brackish waters were encountered at lower elevations, the denser waters having acted more or less as barriers; thus the fresh waters have tended to move southeastward and northeastward. Hence down-warped strata of the wdge-shaped area between the lower James and the mouth of the Rappahannock continue to be filled with brackish water whereas in the adjacent area the same strata contain fresher water.

The apex of the wedge-shaped area of high chloride water does not coincide exactly with the indentation shown by the structural contours drawn on the base of the Eocene formations. The westward apex of the high chloride zone lies in western James City County, whereas the structural contour lines at 500, 600, and 700 feet form an apex somewhat north of this point in western Gloucester County. Furthermore, the boundary of the high chloride zone trends to the northeast of its apex, whereas the structural contours trend north-northeast from Gloucester County. Much greater correspondence between the chloride content of the water and the structure is apparent south of York River. The lack of a similar close correlation in the area to the north may be due to the fact that north of York River the Eocene formations are commonly water bearing. If sands of the deeper lying Potomac group of sediments in that area were the only water-bearing formations sampled it is thought that a closer correlation between the structure of the beds and the quality of water would be obtained. Differences in artesian head whereby a stronger eastward flow and a stronger flushing action in the northerly area have completely removed the brackish waters from sediments may also be a contributing factor. Higher artesian head might result from differences inherent in the two areas, such as in elevation of the intake area and thicknesses and permeability of the strata. Higher water levels and greater eastward and southeastward flow might also result from the fact that north of Fredericksburg, through Washington, D. C., and Baltimore, Md., to Wilmington, Del., the Fall Zone trends sharply to the northeast, in consequence of which the counties at the eastern end of the Rappahannock-Potomac peninsula are receiving recharge from the north as well as from the west, whereas the southerly counties are receiving recharge only from the west. Much more field work will be necessary before the basic geologic and hydrologic elements of the northern part of the Virginia Coastal Plain are fully understood.

VARIATIONS IN CHLORIDE CONTENT

It is a matter of great importance to many users to know whether or not the chloride content of water from wells in the high chloride zone will increase after months or years of continuous discharge. In at least one heavily pumped area in the Coastal Plain of Virginia the chloride content of the well water increased temporarily but the danger of a similar or greater permanent increase is slight in most places because pumping is at a minimum. It is believed, however, that under conditions of heavy pumping well water throughout the high and



Cross sections showing geologic structure and chloride content of artesian water of part of the Virginia Coastal Plain south of Potomac River. Vertical exaggeration, 33X. By D. J. Cederstrom.

intermediate chloride zone and in the low chloride area immediately adjacent to the intermediate zone, will have a definite tendency to increase in chloride content.

The study of chloride increase has been approached in three ways: Analyses were made of water from wells which had been sampled twenty to forty years ago and the results were compared; changes in the quality of water from certain wells have been correlated with discharge; and a program of periodic sampling of certain wells which are discharged more or less continuously has been initiated and is being continued.

Comparison of recent analyses with older analyses.—In 1918, several wells were sampled by members of the Federal Geological Survey. In February, 1941, as many of these wells as could be located, and many other wells for which older analyses were available, were sampled again by the writer. The comparative results are included with other data in Tables 1 to 14. These data may be summarized as follows: Reliable comparative analyses show that waters from a few wells have increased slightly in chloride content, as at the Gloucester Point Hotel well; the well at Whitestone, Lancaster County; Old Baily No. 1 well at Fort Eustis; and the Hotel Corporation well at Yorktown. The apparent increases of chloride in these waters in 20 years or more are 8, 27, 50, and 13 parts per million, respectively. An increase of 50 parts per million has occurred in the water from a well at the Norfolk waterworks but this increase may possibly be ascribed to greater proportionate flow from deeper formations now than formerly. The apparent increase at Achilles, Freeport, Naxera, and Severn, in Gloucester County, may be real but should be accepted cautiously because the analyses by Sanford were field analyses and thus probably were not as accurate as laboratory analyses.

Several wells now appear to yield water with a lower chloride content than in 1918; for example, the L. W. Lane well, at Jamestown; the 610-foot well of the Kilmarnock Fish Company, Kilmarnock; the well at Taft, Lancaster County; the Fitzhugh well at Urbanna, Middlesex County; the two wells at Fleeton; and the Reedville well, Northumberland County. The apparent decreases of 2, 6, 5, 7, 2, 2, 3, and 3 parts per million, respectively, are probably not significant because the differences are not much greater than the possible uncertainty in the analyses unless special care is taken. The decrease of 37 parts per million at Almondsville, Gloucester County, may perhaps be ascribed to an error in sampling at one time or another.

Pump tests.—The second method has been to study the effects of varying rates of discharge during a brief pumping period upon the chloride content of the water.

In the fall of 1940, the U. S. National Park Service kindly made a test run of the well which in part supplies Yorktown. The well had been idle for many months previous to the test run. From September 21 to 29, inclusive, the well was pumped eight hours a day, generally from 8:00 A. M. to 4:00 P. M., at a rate of about 118 gallons a minute. Samples were taken at the beginning and end of each run. On September 30 the well was started at 8:00 A. M. and was run continuously for 52½ hours. Samples were taken during and at the conclusion of the test.

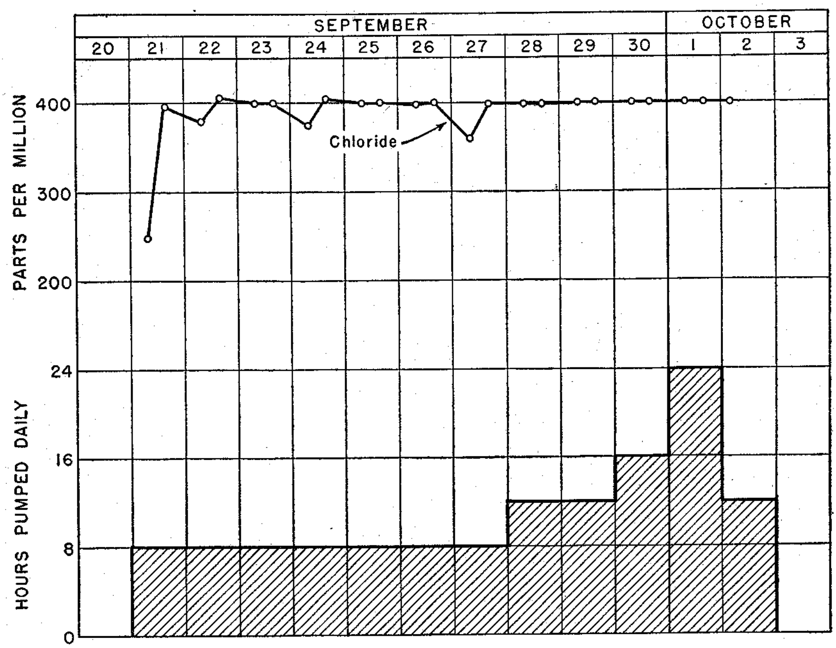


FIGURE 3.—Graph showing relation of chloride content to quantity of water pumped at Yorktown, Va., during 12-day test, September 21 to October 2, 1940. A low chloride is characteristic of the water in periods of small discharge, but when the well is pumped regularly the chloride content of the water rises.

The results of this test are shown in Figure 3. The first sample contained 248 parts per million of chloride but towards the end of the 8-hour period the chloride content was 390 parts. At the beginning of the run on the second day the chloride content was 380 parts per million and near the end of 8 hours of operation it was 405 parts per million. On the third day, both samples contained 400 parts of chloride. At the beginning of the fourth day the chloride content was 375 parts, but at the end of the 8-hour pumping period it was 405 parts. Samples taken on the fifth and sixth days contained about 400 parts, but the first sample on the seventh day contained 360 parts. During the remainder of the test, all samples taken contained about 400 parts per million. This test indicates that when the well is not in service the chloride content of the water will be less than 250 parts per million but upon resumption of service the chloride content will increase to about 400 parts. If operated intermittently or for only a part of each day, the chloride content at the beginning of each period may be somewhat less than 400 parts per million.

Officials of the National Park Service have continued to sample the water from the Yorktown well and have furnished data on the amount of water pumped in 1941. In the spring of 1941 the chloride content remained at about 400 parts per million but 3 days after the cessation of relatively heavy pumping the chloride content dropped to 210 parts per million (Fig. 4). This sample was taken June 5, after pumping 2½ hours. The well remained idle until August 1, when a sample taken, after pumping half an hour, contained 205 parts of chloride. The well was then put into more or less continuous service for the remainder of the year. Samples taken September 2 and subsequent samples contained 400 parts per million of chloride.

Chloride observation program.—In the Lee Hall area, samples from several wells are being collected regularly and analyzed for the chloride content. Because of the military importance of the area the results of such studies may be discussed only in general terms.

Waters from two wells at Fort Eustis showed increases of chloride content soon after construction in 1941, when the wells were put into regular use. The chloride in the water from one increased 4½ per cent and the other increased about 9 per cent. The wells yielded water of the higher chloride content from that time, and in this respect their history is similar to that of the Yorktown well as shown in Figures 3 and 4.

With the construction of a new well of large yield nearby early in 1942, and the general increase in the amount of water withdrawn from the ground by all active wells, the water from one old well showed a 16 per cent increase in chloride content and one of the newer wells yielded water with 10½ per cent more chloride than was present in the water in the fall of 1941. Samples collected shortly thereafter showed that this increase was not maintained. Although temporary, the increase was significant and indicative of an ever-present danger in a heavily pumped chloride area.

The variations of chloride content in waters from wells in the Lee Hall area are interesting and important. The observation program as a part of the cooperative project, between the State and Federal Geological Surveys, will be followed closely in order

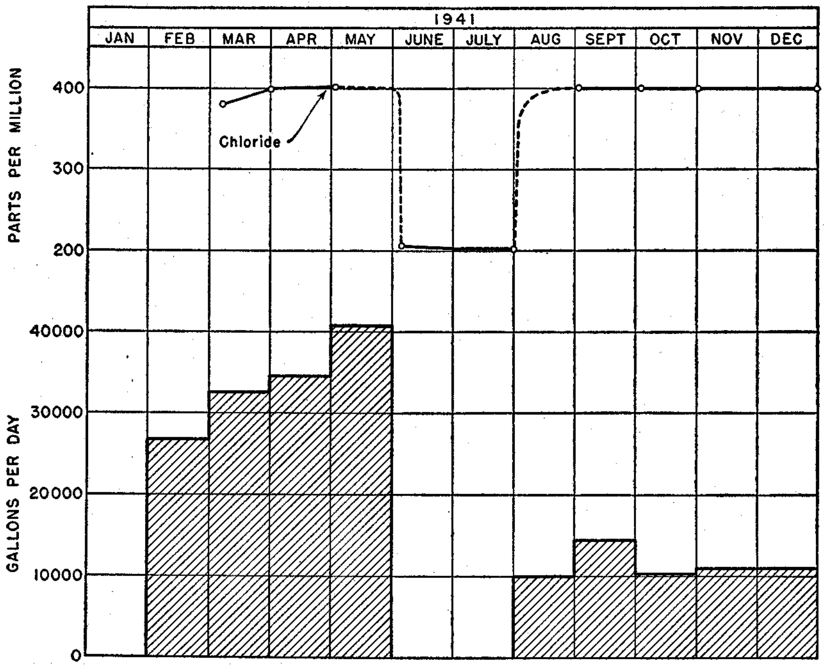


FIGURE 4.—Graph showing relation of chloride content to quantity of water pumped at Yorktown, Va., in 1941.

that the chloride problems may be more thoroughly understood and that information applicable not only to present installations but also to future developments in the Coastal Plain will be available.[9]

Summary.—It appears from the available data that when a well in the high chloride zone of the Virginia Coastal Plain is put into intermittent or continuous operation, the chloride content of the discharged water may rise rapidly and then tend to remain constant. Increasing the rate of withdrawal, the total amount of water pumped per day, or the total amount of discharge in a limited area, may cause the chloride content to increase still further. It is not certain that the chloride will remain constant after each new "high" is reached. In an over-pumped area, gradual increases of chloride may continue after an initial sharp rise. Is is thought that chloride increases are probable where observations of water levels show that the cone of depression in a discharge area is

[9] See report on "Water levels and artesian pressure in observation wells in the United States in 1942" and succeeding annual reports, to be published as U. S. Geological Survey Water Supply Papers, for yearly summaries of the chloride observation program in Virginia.

growing, an indication that equilibrum has not been attained between the amount of water entering the area as recharge and the amount being discharged by the wells.

Throughout the zone of high chloride waters no pumping of significance is taking place except in the vicinity of Lee Hall. Therefore, the increases in chloride that have been observed in a few other places must be ascribed to some other cause. It is thought that a local or regional decline of artesian head of the upper strata due to the construction of flowing wells may have resulted in a greater proportionate flow of water of higher chloride content from deeper horizons. Decreases have also occurred and they may, perhaps, be ascribed to factors that cause a decrease in the flow from depth. Diminished flow from depth may result when the artesian head in both deep and shallow strata equalizes and the volume of water discharged becomes smaller. Similar results would be expected if, as suspected, sand clogging has diminished the flow of many domestic wells.

Most of the changes in chloride content of waters in the areas of flowing well discharge may be explained by variations in head or volume of discharge. In rare instances leaky casings may admit water of different chloride content which may be considered as the factor responsible for the observed changes.

CHLORIDE CONTENT OF SHALLOW GROUND WATER

Along the shores of Chesapeake Bay and along the banks of the larger rivers traversing Tidewater Virginia, dug wells 20 to 30 feet deep, and driven wells generally less than 100 feet deep, obtain small quantities of fresh water. Most of these wells yield water containing very little chloride in spite of their proximity to the rivers or to the bay. Waters from several of these wells, for which analyses are available, do contain chlorides in excess of 20 or 30 parts per million and in some places "salting" of shallow well fields has occurred as a result of the lateral migration of brackish waters.

OCCURRENCE OF SHALLOW GROUND WATER

Water occurring in homogeneous sands near the surface, as in terrace formations or in beach sands, fills the voids between the rock particles of the formations to a level known as the water table. That part of the formation which is filled with water, that is, below the water table, is in the zone of saturation. In the Coastal Plain of Virginia the thickness of the saturated part of the shallow sands is limited by the underlying impermeable marls and thus it extends only a relatively short distance below the water table. Shoreward

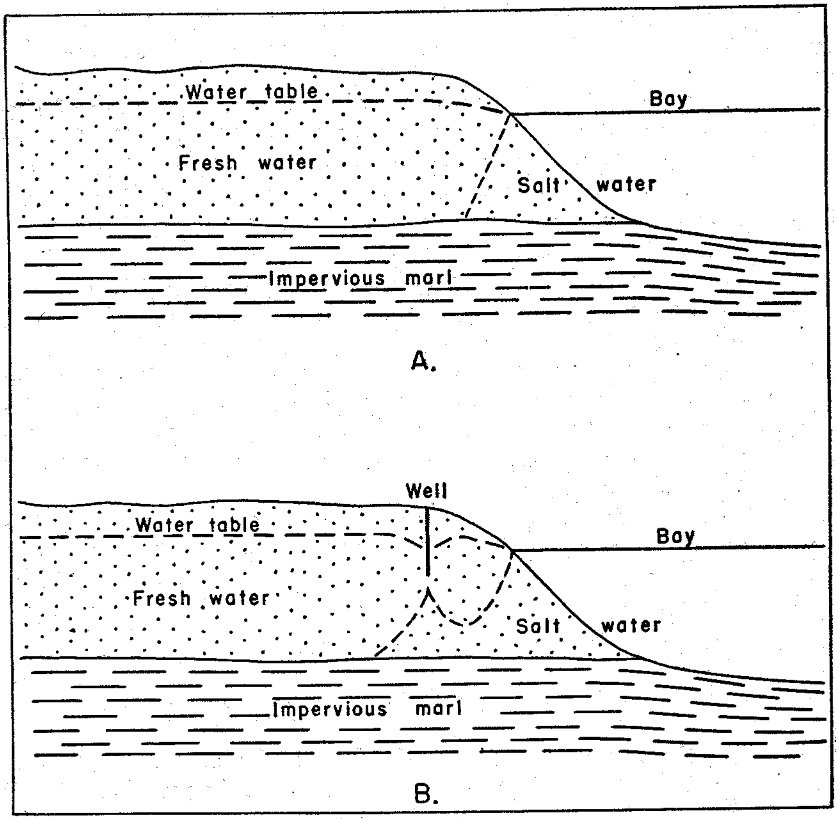


FIGURE 5.—Diagrams showing relation of fresh water to salt water along the coast: A, under static conditions; B, under pumping conditions.

towards the rivers and the bay the fresh water which fills the sand deposit is in contact with the salt or brackish water and because it is lighter, if not disturbed, it will not mix very much with the salt water. These relationships are shown in Figure 5A. If a well located near the contact between the fresh and salt water is pumped heavily, however, salty water will tend to be drawn into the well as the head of fresh water is lowered (Fig. 5B). With continued heavy pumping the well may yield water about as salty as that of the adjacent bay or river.

In some places wells less than 100 feet deep penetrate thin water-bearing formations which are included in the impervious marl shown in Figures 5A and 5B. These formations dip gently eastward and may be more or less open to brackish river or bay water in some places. The water in these formations is under low artesian head and hence brackish water tends to be forced out. However, if the head is greatly lowered near the coast by heavy pumping, brackish water may enter the formation and contaminate the wells.

SOURCES OF CHLORIDE

Almost all small well installations along rivers, bays, and the ocean are free of chloride contamination. Most of these wells are located a hundred feet or more from the shore and very few are pumped heavily. The chloride content of the waters yielded by these wells is generally less than 100 parts per million and in places is less than 25 parts per million. The chloride is due in large part to salt spray which is blown over the land and then carried down into the water-bearing formations by rain and ground water. This is thought to apply particularly to the chloride found in wells in the Eastern Shore peninsula. It is also probable that the chloride content of many waters from dug wells is in large part due to organic pollution since many of these waters also show an excessively high nitrate content.

CONTAMINATION OF SHALLOW WELLS

A few instances are known of contamination by brackish waters. At the Buxton Hospital in Newport News, on the north shore of the James, a group of five driven wells from 22 to 37 feet deep were pumped continuously at a rate of 25 gallons a minute. The water was used for air-conditioning. After several months of pumping, however, the water became so brackish that its use had to be discontinued.

According to Sanford,[10] the town of Cape Charles obtained its water supply from one open well, 20 feet deep, and 17 driven wells, 3 of which were 40 feet deep and 14 of which were of less depth. These wells were located in the lower part of the town near the water front. It is reported that the water from them became brackish, necessitating the installation of the present deeper wells located on higher ground about half a mile east of the shore of Chesapeake Bay.

Although only a few instances are known where salt water contamination has occurred, the danger of chloride contamination is real in coastal areas, and where installations designed to furnish water in quantity are contemplated, definite steps should be taken to guard against this danger.[11] In brief, wells should be located a

[10] Op. cit., pp. 245, 246.

[11] Cederstrom, D. J., Ground water in the Virginia Beach area, Virginia, Memorandum report to W. R. Hatchett, Municipality of Virginia Beach, unpublished manuscript, U. S. Geological Survey, April 25, 1941.

mile or more back from the shore, they should be aligned more or less parallel to the coast, and in general several wells yielding moderate quantities of water are preferable to fewer wells of large yields. When a well field is constructed, periodic determinations of the quality of the water from the pumped wells and from observation wells located between the shore area and the area of pumping should be regular routine.

CHLORIDE CONTENT OF DEEP WELL WATERS, BY COUNTIES

Tables 1-14 give the basic data on the chloride content of well waters and sufficient additional information to locate and identify the wells. For many of the wells data are given by which recent analyses may be compared with analyses made in previous years. The older analyses are largely those published in Bulletin 5 of the Virginia Geological Survey[12] and unpublished analyses by Riffenburg.[13]

[12] Sanford, Samuel S., The underground water resources of the Coastal Plain of Virginia: Virginia Geol. Survey Bull. 5, 1913.

[13] Riffenburg, H. B., The chemical character of ground water in the Coastal Plain of Virginia: U. S. Geol. Survey, unpublished manuscript, 1918.

TABLE 1.—*Chloride content of artesian waters in Gloucester County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
Achilles	Union Baptist Church	600	5	1500	1906	S. Sanford (F)
do	do	600	5	1540	June 19, 1918	H. B. Riffenburg
Almondsville	W. R. Seward	270	10	106	1906	R. B. Dole
do	do	270	10	69	Feb. 12, 1941	M. D. Foster
Cappahosic	Gloucester A. & I. School	395	15	54	June 19, 1918	H. B. Riffenburg
do	do	395	15	53	Feb. 12, 1941	M. D. Foster
Freeport	E. C. Farinholt	330	15	25	1906	S. Sanford (F)
do	do	330	15	36	Feb. 13, 1941	M. D. Foster
Gloucester	Town	810	75	345	Feb. 12, 1941	M. D. Foster
Gloucester Point	Hotel	694	10	410	1906	S. Sanford (F)
do	do	694	10	424	June 18, 1918	H. B. Riffenburg
do	do	694	10	432	Feb. 11, 1941	M. D. Foster
Naxera	A. M. Withers	716	6	1630	1906	R. B. Dole
do	do	716	6	1700	Feb. 13, 1941	M. D. Foster
Sassafras	B. F. Weaver	336	5	220	1906	S. Sanford (F)
Severn	J. M. Shackelford	575	8	2500	1906	R. B. Dole
do	do	575	8	2675	Feb. 12, 1941	M. D. Foster

TABLE 2.—*Chloride content of artesian waters in Isle of Wight County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
Bens Church	R. B. Wood	475	15	5	Nov. 12, 1937	W. M. Noble
Carrolton	Brennan	480	6	25	Nov. 10, 1937	do
do	N. N. Bridge Corpn	457	6	55	Nov. 10, 1937	do
Central Hill	W. D. Joyner	419	90	2	Nov. 20, 1937	do
Franklin	Chesapeake—Camp Corpn.	600	20	10	Nov. 27, 1941	M. D. Foster
Isle of Wight	High School	444	55	1	Nov. 20, 1937	W. M. Noble
Mogarts Beach	Roy Conklin	360(?)	30	14	Oct. 20, 1918	C. S. Howard
do	do	375	10	10	Nov. 10, 1937	W. M. Noble
Rescue	J. H. Carter	405	15	25	Nov. 10, 1937	do
Rushmere	M. L. Marshall	350	10	13	Oct. 19, 1918	A. T. Geiger
do	do	350	10	12	Nov. 10, 1937	W. M. Noble
Smithfield	Smithfield Water Corpn.	330	15	4	Nov. 20, 1937	do
Zuni	P. H. Doles	210	18	2	Nov. 20, 1937	do

TABLE 3.—*Chloride content of artesian waters in James City County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
Diascund	J. T. Wall	216	10	11	Feb. 10, 1941	M. D. Foster
Jamestown	C. F. Ayers	300	20	13.5	1906	S. Sanford (F)
do	do	300	20	14	Feb. 6, 1941	M. D. Foster
do	R. B. Watts	376	30	12	Dec. 19, 1942	E. W. Lohr
do	L. W. Lane	311	20	9.6	Oct. 18, 1918	A. T. Geiger
do	do	311	20	7	Feb. 6, 1941	M. D. Foster
Norge	C. & O. Railroad	419	100	176	1910	Froehling & Robertson
Toano	Menzel Brothers	117	10	4	Feb. 7, 1941	M. D. Foster
Williamsburg	Eastern State Hospital	268	70	107	1910	W. H. Taylor
do	do	417	70	255	Feb. 7, 1941	M. D. Foster
do	William and Mary College	412	70	225	Feb. 7, 1941	do

TABLE 4.—*Chloride content of artesian waters in King William County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
West Point	Chesapeake Pulp Co.	140	20	11	Feb. 11, 1941	M. D. Foster
do	do	335	20	12	Feb. 11, 1941	do
do	do	400	20	11	Feb. 11, 1941	do
do	Town	335	20	17	1906	S. Sanford (F)
do	do	379	20	11	Feb. 10, 1941	M. D. Foster

TABLE 5.—*Chloride content of artesian waters in Lancaster County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
Irvington	B. Willing	750	10	11	Feb. 28, 1941	M. D. Foster
Kilmarnock	K. Fish Prod. Co.	480	5	4.5	July 5, 1918	A. T. Geiger
do	do	610	5	11	July 5, 1918	do
do	do	610	5	6	Feb. 27, 1941	M. D. Foster
Ocran	Standard Products Co.	600	5	14	July 5, 1918	A. T. Geiger
do	do	600	5	14	Feb. 27, 1941	M. D. Foster
Taft	W. H. Culver	560	5	40	July 5, 1918	A. T. Geiger
do	do	560	5	33	Feb. 27, 1941	M. D. Foster
Whitestone	Little Bay Ice Co.	580	8	86	July 5, 1918	H. B. Riffenburg
do	do	580	8	113	Feb. 28, 1941	M. D. Foster

TABLE 6.—*Chloride content of artesian waters in Mathews County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
Mathews C. H.	Town	817	2	156	June 17, 1918	H. B. Riffenburg
North	G. W. Billups	460	5	550	June 14, 1918	do
do	do	460	5	552	Feb. 13, 1941	M. D. Foster

TABLE 7.—*Chloride content of artesian waters in Middlesex County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
Remlik	Lord Mott Cannery	471	1	6	June 5, 1918	H. B. Riffenburg
do	do	471	1	5	Feb. 13, 1941	M. D. Foster
Urbanna	Wm. Fitzhugh	480	5	6	June 5, 1918	H. B. Riffenburg
do	do	480	5	4	Feb. 13, 1941	M. D. Foster
do	J. W. Hurley	478	6	6	June 5, 1918	H. B. Riffenburg
do	do	478	6	5	Feb. 13, 1941	M. D. Foster

TABLE 8.—*Chloride content of artesian waters in Nansemond County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
Belleville	J. Ames	600	15	87	Aug. 5, 1939	M. D. Foster
Bentons Store	Shamrock Farm	480	8	11	Aug. 5, 1939	do
Chuckatuck	Lone Star Cement	580	15	8.2	Aug. 4, 1939	do
Cypress	Chesapeake Camp	420	30	26	Aug. 4, 1939	do
do	School	342	60	12	Oct. 3, 1939	do
Town Point	W. R. Old	550	15	68	Aug. 5, 1939	do
Drivers	Ebberwine Cannery[a]	550	20	67	Oct. 4, 1939	do
Eclipse	E. L. Murtig	650	20	94	Aug. 4, 1939	do
Everetts Bridge	H. H. Schramm	360	15	7	Nov. 12, 1937	W. M. Noble
Hobson	Adams Oyster Co	525	12	15	Oct. 3, 1939	M. D. Foster
Lake Prince	City of Norfolk	[b]600	65	5	Aug. 14, 1942	E. W. Lohr
do	do	[b]810	65	15	Aug. 18, 1942	do
do	do	[b]852	65	20	Aug. 22, 1942	do
South Quay	Frank Johnson	235	28	4	Aug. 6, 1939	M. D. Foster
do	W. A. Jones	427	30	34	Aug. 6, 1939	do
Suffolk	City[c]	[d]515	19	18	Aug. 8, 1929	W. L. Lamar
Suffolk	do	717	19	25	Sept. 14, 1929	do
do	do	717	19	26	Aug. 4, 1939	M. D. Foster
Whaleyville	T. O. Knight	365	70	7	Aug. 4, 1939	do

[a] Water analyzed two years later showed no change in chloride content.
[b] Test hole, total depth 970 feet.
[c] Test well installed by city.
[d] Well sampled at 515 feet at time of construction.

TABLE 9.—*Chloride content of artesian waters in Norfolk County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
Craney Island	Fuel Depot	590	10	258	Nov. 4, 1939	M. D. Foster
Norfolk	Norfolk and Western Railroad	616	20	351	1891	C. W. Shepard Lab.
do	do	616	20	300	Nov. 4, 1939	do
do	do	616	20	291	1906	N. & W. R. R.
do	Waterworks	1762	15	1030	1906	S. Sanford (F)
do	do	1762	15	1080	Aug. 30, 1939	M. D. Foster
do	O. D. Peanut Co.	720	10	408	Aug. 31, 1939	M. D. Foster
West Norfolk	Virginia Smelting & Refining Co.	605	7	260	1938	W. F. Pond
Twin Pines	H. L. Trottman	520	10	196	Sept. 6, 1939	M. D. Foster

TABLE 10.—*Chloride content of artesian waters in Northumberland County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
Fleeton	Douglas Fish Co.	740	8	10	July 2, 1918	A. T. Geiger
do	do	740	8	8	Feb. 27, 1941	M. D. Foster
do	Town	680	8	10	July 2, 1918	A. T. Geiger
do	do	680	8	7	Feb. 27, 1941	M. D. Foster
Lewisetta	Garner Brothers	550	5	3.9	July 5, 1918	A. T. Geiger
do	do	550	5	3	Feb. 27, 1941	M. D. Foster
Reedville	R. B. Morris	740	5	10	July 1, 1918	H. B. Riffenburg
do	do	740	5	7	Feb. 27, 1941	M. D. Foster
Walnut Point	A. J. Lewis	340	5	2.7	July 3, 1918	A. T. Geiger
do	do	605	5	4	July 3, 1918	H. B. Riffenburg

TABLE 11.—*Chloride content of artesian waters in Southampton County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
Baffle	Black Creek School	270	62	1.0	Sept. 14, 1937	W. M. Noble
Burdette	J. B. Joyner	130	26	2.0	Sept. 14, 1937	do
Courtland	W. J. Manry	135	30	16	Apr. 20, 1938	do
do	High School	230	30	18	Sept. 25, 1937	M. D. Foster
Courtland[a]	T. L. Baine	438	30	23	Sept. 25, 1937	do
Franklin[b]	Virginia Department of Highways	150	20	2.0	Sept. 15, 1937	do
Franklin[c]	S. W. Rawls	158	20	88	Oct. 1, 1937	do
do	R. C. Motor Co.	353	15	4.0	Sept. 15, 1937	do
Ivor	Public School	278	88	3.0	Sept. 15, 1937	do
Sedley	do	270	93	2.0	Sept. 14, 1937	do
do	Virginian Railroad	630	85	8.0	Nov. 27, 1937	do

[a] Two miles southeast of town.
[b] South edge of town.
[c] Seven miles south of town.

TABLE 12.—*Chloride content of artesian waters in Surry County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
Bacons Castle	Church	360	80	4.0	Oct. 4, 1939	M. D. Foster
do	City of Newport News	[a]560	70	3.0	Jan. 24, 1942	do
do[b]	do	[c]711	95	4.4	Feb. 12, 1942	do
do[b]	do	[d]799	95	3.2		
Cobham Wharf	R. W. Berryman	288	15	2	Nov. 4, 1939	do

[a] Water obtained from stratum at 550 feet to 574 feet below surface.
[b] Test well 3.2 miles south of Bacons Castle.
[c] Water obtained from stratum at 693 feet to 711 feet below surface.
[d] Water obtained from strata at 388 feet to 711 feet below surface.

TABLE 13.—*Chloride content of artesian waters in Warwick County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
Denbigh	C. P. Yoder	517	10	455	Feb. 26, 1942	M. D. Foster
Morrisson	J. R. Country Club[a]	738	15	512	July 2, 1935	R. L. Angell
do	do	738	15	495	Aug. 5, 1940	M. D. Foster
do	J. R. Country Club[b]	732	15	755	Aug. 5, 1941	do
do	Mariners Museum	1000	7	660	Feb. 26, 1942	do
Mohea	A. M. Miller	510	20	360	Feb. 26, 1942	do
Newport News	Buxton Hospital	820	20	1680	Aug. 5, 1940	do
do	Levinson Meat Packing Co.	900	20	690	Dec. 12, 1940	do

[a] Well located at swimming pool.
[b] Well located at fish pond.

TABLE 14.—*Chloride content of artesian waters in York County, Virginia*

Location	Owner	Depth (feet)	Approximate elevation (feet above sea level)	Chloride (p.p.m.)	Date	Analyst
Grove	E. W. Harwood	554	10	524	Oct. 17, 1918	A. T. Geiger
Pennimen	E. I. Dupont	495	20	404	Oct. 17, 1918	do
do	Bectel Farm	414	20	985	Feb. 7, 1941	M. D. Foster
Magruder	Marshall Estate	285	20	103	1900 (?)	W. H. Taylor
do	U. S. Navy	445	35	382	Nov. 10, 1942	S. K. Love
Yorktown	U. S. Navy[a]	480	15	454	Feb. 7, 1941	M. D. Foster
do	U. S. Navy[b]	470	18	574	Nov., 1941	Commercial
do	Hotel Corporation	400	5	375	Aug. 24, 1931	M. D. Foster
do	do	400	5	388	Feb. 8, 1941	do
do	Colonial National Park[c]	700	50	1800	Aug. 28, 1931	do
do	do	420	50	565	Sept. 13, 1931	do

[a] **Well constructed in 1918.**
[b] **Well constructed 1941.**
[c] **Because of the high chloride content, strata below 400 feet were cased off. See alsoFigures 3 and 4.**

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